4.5 Case V: Cloud Plumes in the Arctic

4.5.1 Introduction

The existence of cloud plumes, emanating from selected islands and/or adjoining polynyi in the Arctic, has attracted attention since Kienle et al. (1983) suggested a possible volcanic origin for plume development near Bennett Island (Ostrov Bennetta) in the East Siberian Sea. Matson (1986), reported on another plume, this one emanating from the vicinity of Novaya Zemlya, an island that separates the Kara Sea from the Barents Sea. Matson also suggested a geomorphic or anthropomorphic origin for this case plume (see Chapter 5, Section 5.2). Parmenter-Holt (1987) argued rather convincingly that the latter plume was not geomorphic or anthropogenic but rather a naturally occurring, orographically-induced event, which signaled cloud formation as a result of lee mountain wave activity.

Research at NEPRF substantiated Parmenter-Holt's conclusion as valid for both of the preceding examples and distinguishes differences between orographic plumes and lower level polynya-produced plumes, also often noted during the cold months over the Arctic region. NEPRF further suggested that the orographic plumes are often excellent indicators of Arctic frontal location and associated jet stream activity.

4.5.2 18 February 1983

Figure 4-54, IR NOAA-6 imagery for 18 February 1983, shows the Bennett Island plume that attracted so much early attention. The plume is colder than the surrounding environment, radiating at a temperature of about −45 °C. Zhokhova is the small island outlined in the figure to the east-southeast of Bennett. The 0000 GMT sounding for Zhokhova on 18 February is shown in Fig. 4-55. The sounding indicates that the plume top was located below the tropopause near the 400-mb level. From Fig. 4-54 the source of the plume appears to be over the polynya, apparent as a warm region on the east side of Bennett Island. (Note the polynya effect also apparent on the east side of Zhokhova.) The suggestion that the plume has its source over the polynya, however, is ruled out for two reasons: (1) the low-level inversion shown on the Zhokhova sounding would have been a strong influence tending to prevent the cloud from extending to altitudes above the lowest levels, and (2) data from NOAA-7 at 0047 GMT (Fig. 4-56) reveal that the northernmost plume extends inland, over the island, at that time. A second plume appears slightly southeast of the first plume. Unfortunately the outline of Bennett Island is rather crudely drawn on the original image, used in the 1983 article (Fig. 4-54). A more exact outline of the island, showing topographical features, is shown in Fig. 4-57. This outline was superimposed over the NOAA-7 image and is shown in Fig. 4-58. It reveals that the first plume had developed downstream but in the lee of a 1,398 ft (426 m) mountain; the second southernmost plume also developed in the lee of higher terrain (exact height not specified) near the southeastern tip of the island. Consequently, more than likely both plumes are effects of vertically propagating mountain waves of the type commonly seen in the lee of mountainous terrain over other islands in the Arctic and other regions of the world (see Chapter 5, Subsection 5.5.1). The turbulent appearance of the particular plume of this example is different from the more stratified and striated appearance of many plumes more commonly seen (Subsection 4-5.3). The difference may be attributed to the fact that this particular plume was generated as the result of airflow over an isolated mountain peak, rather than the more commonly seen flow over the crest of a lengthy ridge oriented perpendicular to the prevailing flow.

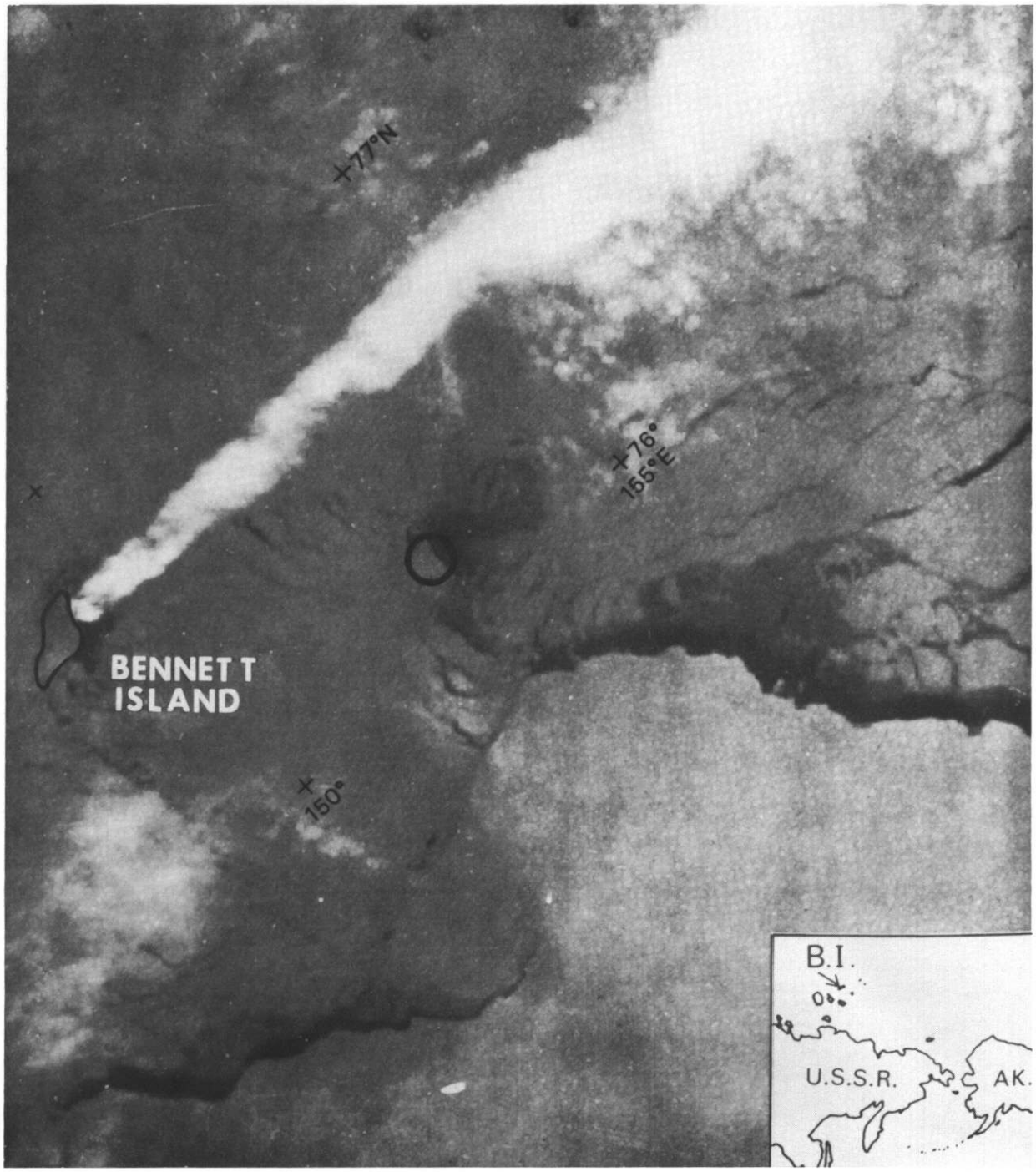

Figure 4-54. IR NOAA-6 Imagery, 0615 GMT 18 February 1983.

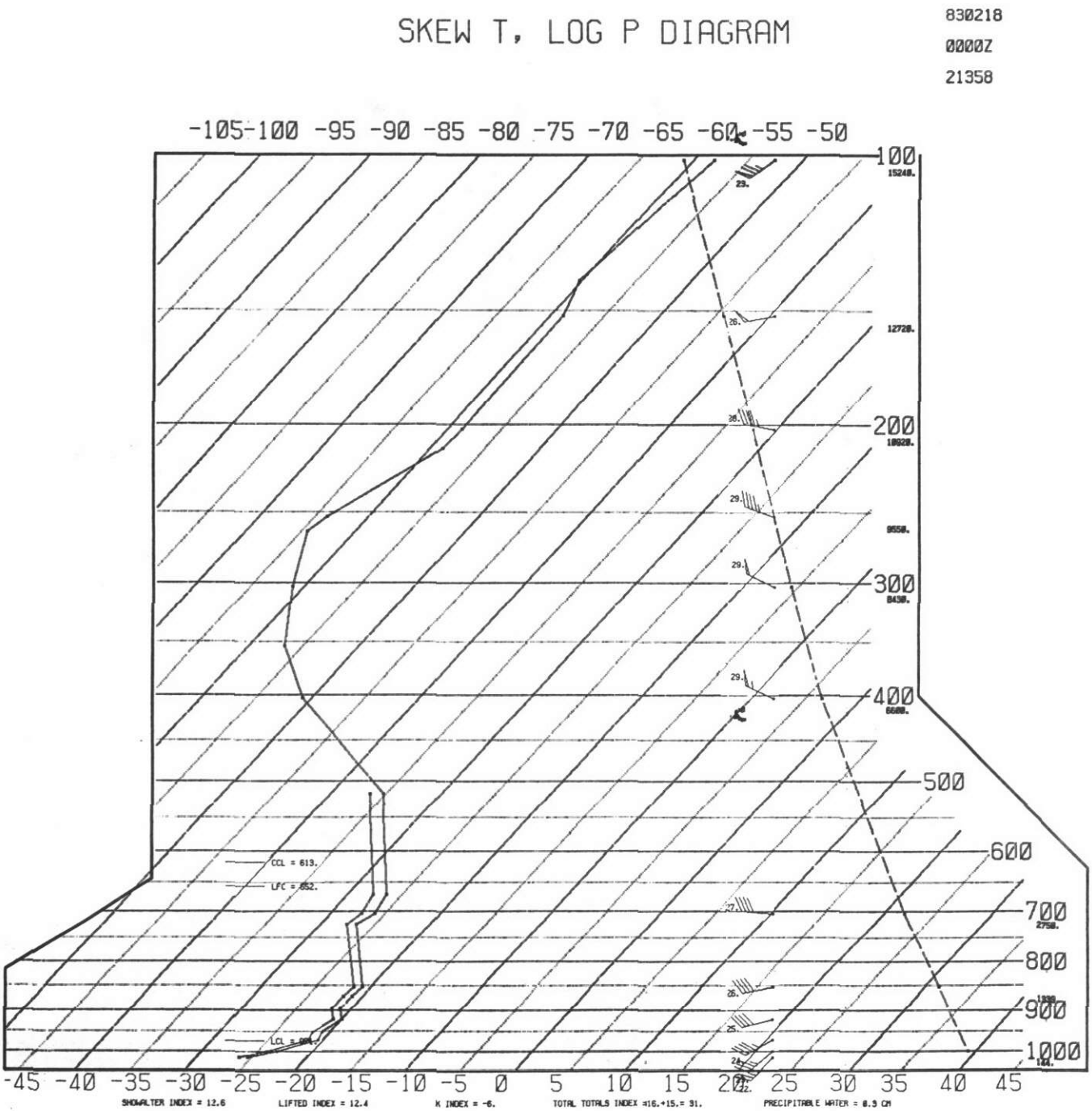

Figure 4-55. Radiosonde Data for Zhokhova Island (Station 21358), 0000 GMT 18 February 1983.

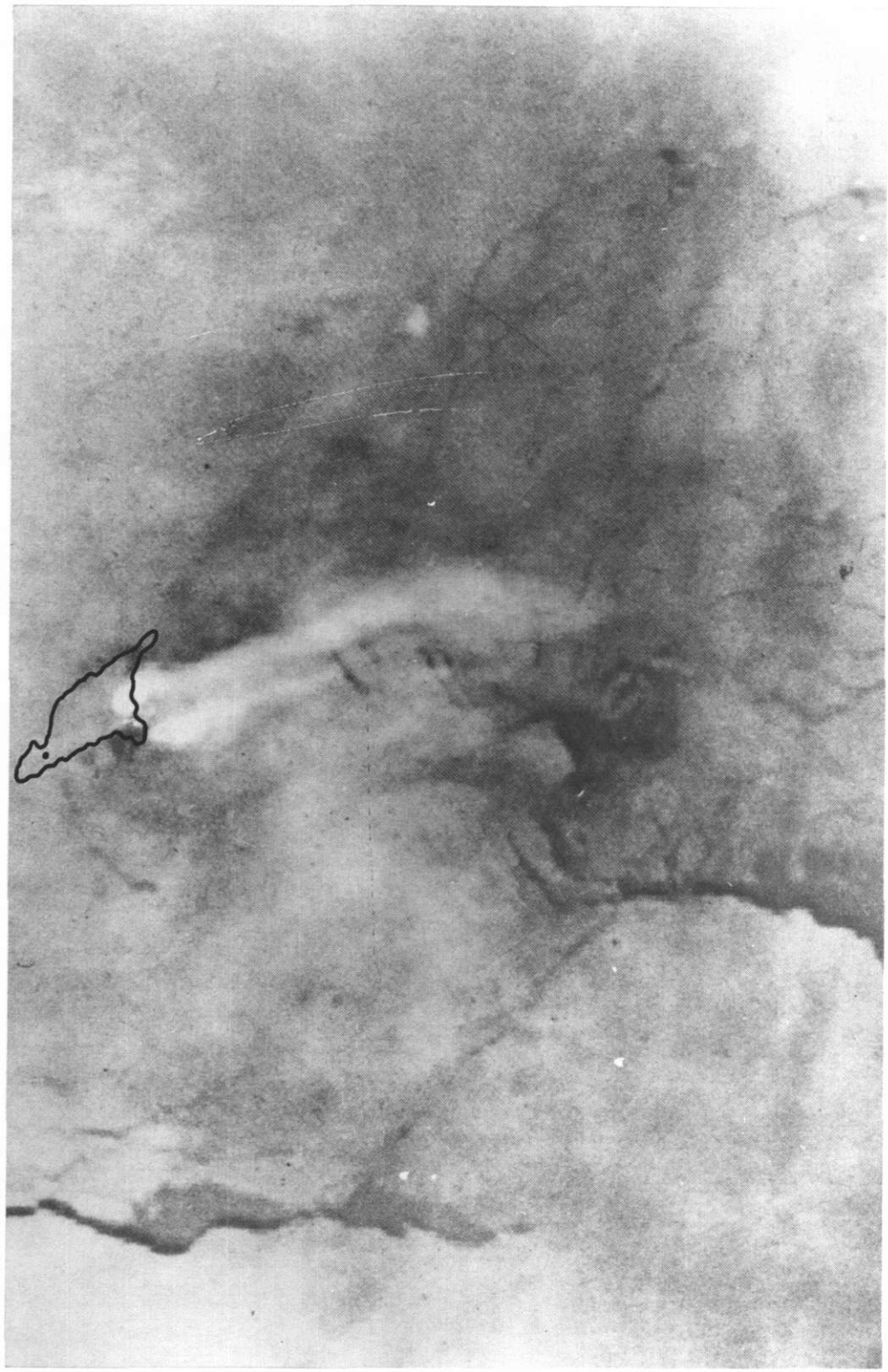

Figure 4-56. IR NOAA-7 Imagery, 0047 GMT 18 February 1983.

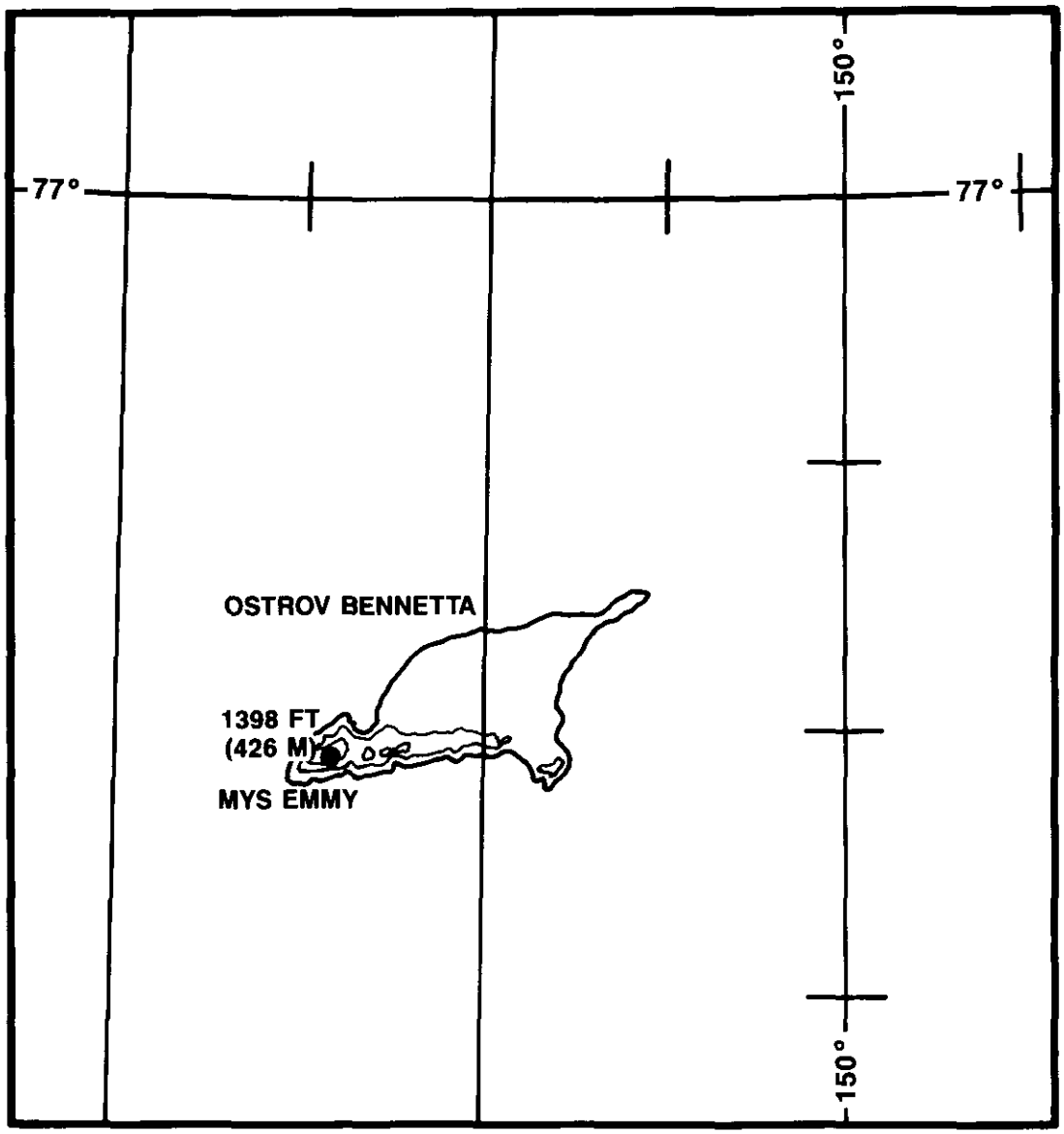

Figure 4-57. Map of Bennett Island.

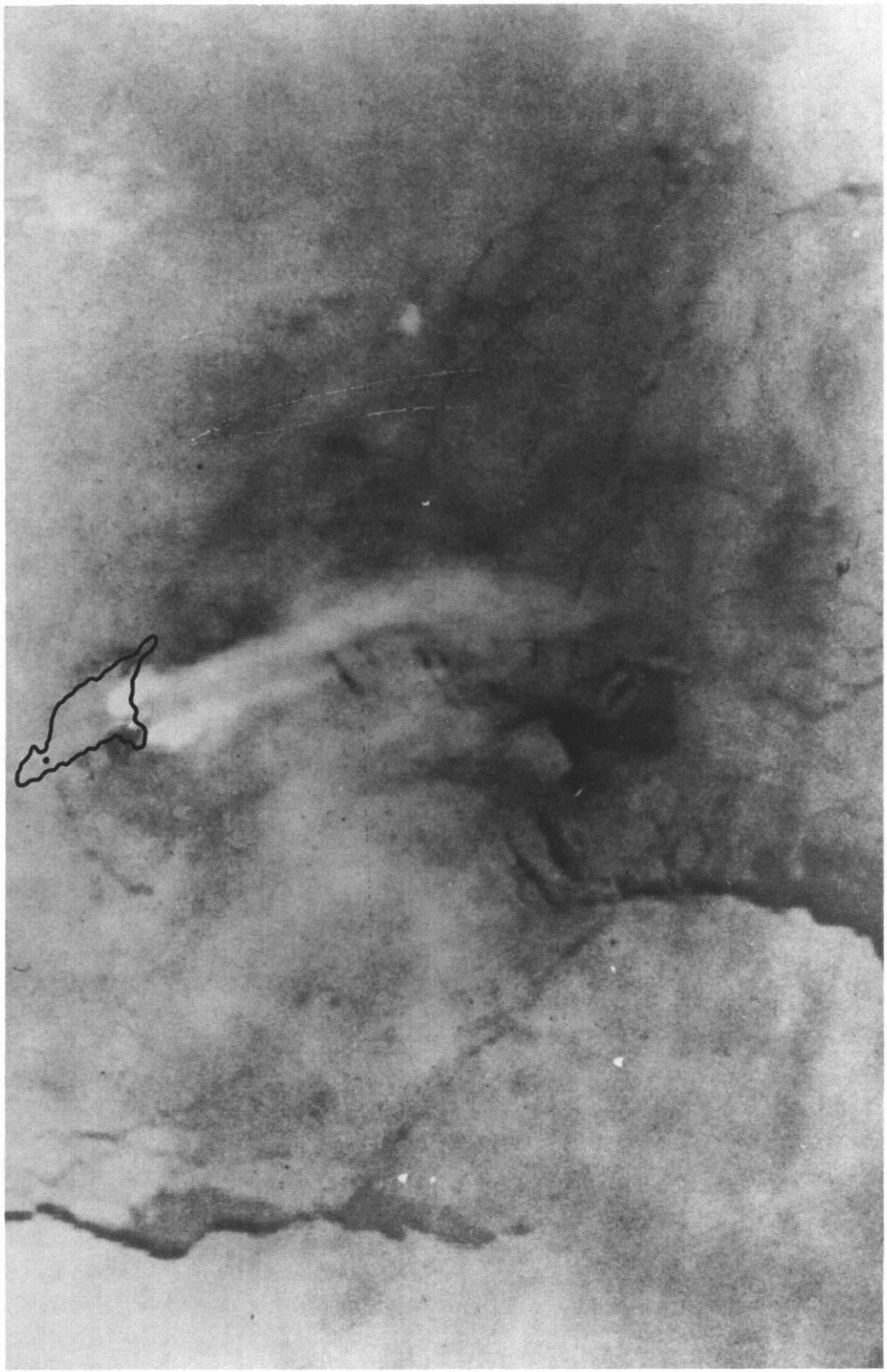

Figure 4-58. IR NOAA-7 Imagery with Outline of Bennett Island Superimposed, 0047 GMT 18 February 1983.

An important consideration to bear in mind is that the apparent plume source region can appear to shift with time, probably depending upon a sudden relaxation, or conversely, intensification, in the strength of the wind flowing over the obstacle. A good example is shown by plume cloud development in the lee of the island of Kvitoya, just east of Svalbard, on 28 March 1987. The image for this example (Fig. 4-59) shows the region as observed by NOAA-10 in IR channel 4 data at 1114 GMT. Apparently the plume's source is the

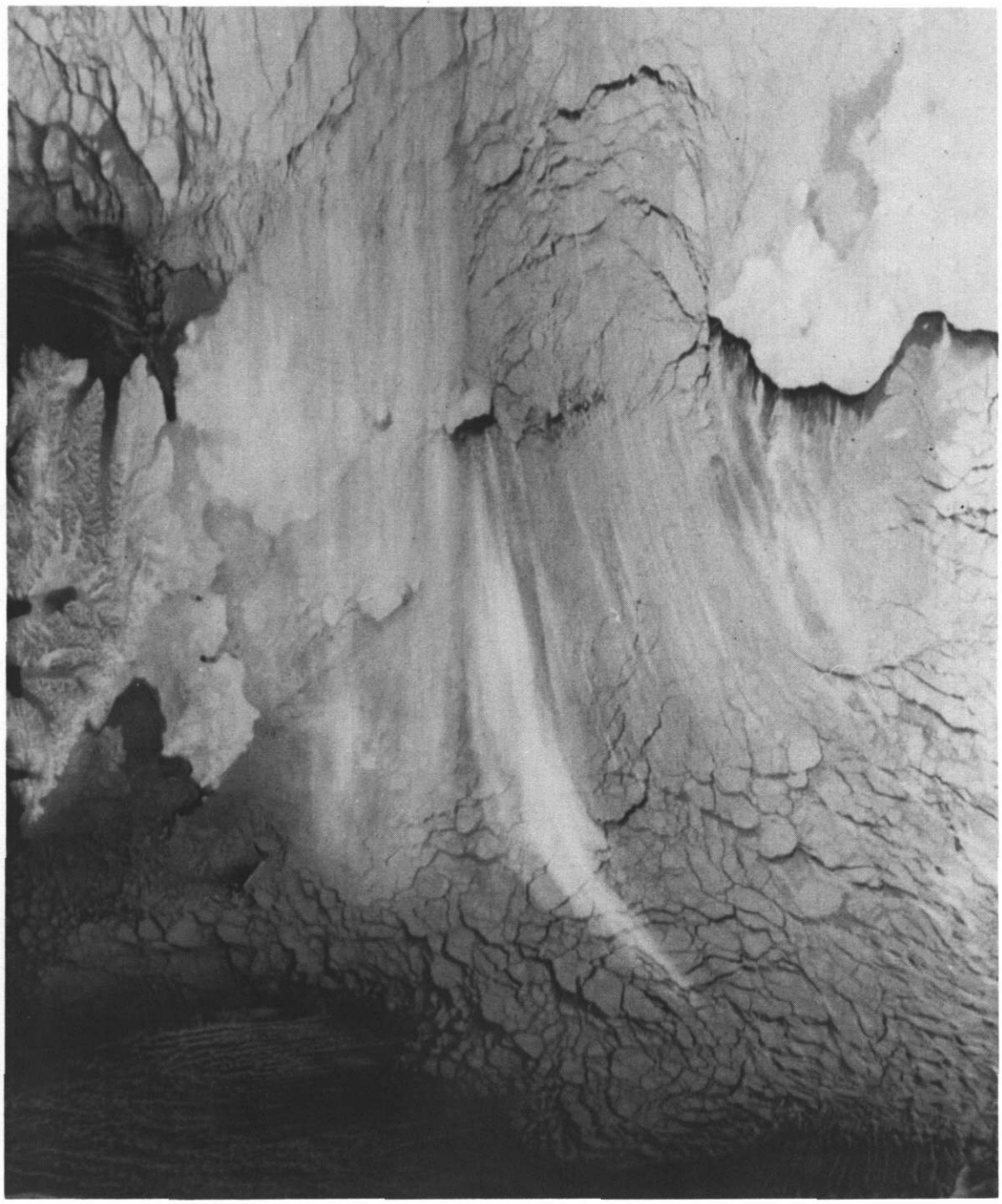

Figure 4-59. IR NOAA-10 (Channel 4) Imagery, 1114 GMT 28 March 1987.

polynya on the south lee of the island. A later NOAA-10 channel 4 view at 1515 GMT (Fig. 4-60) shows, however, the main plume formation very near or even very slightly over the southern shore of the island. A second thinner plume also emanates from the shoreline near the southeastern tip of the island. Figure 4-61 is a map of the island showing that a ridge line exists between two peaks aligned east-west on the island. The width of the ridge line correlates well with the width of the larger plume. The contours indicate an additional separate peak near the southeastern end of the island, which aligns quite well with the thinner cloud plume extending from the shore of the island. Conclusive proof of formation, as a result of island topography, is provided much earlier in the day by IR DMSP (2 n mi resolution) imagery (Fig. 4-62). These data, acquired on 28 March 1987 at 0254 GMT, show plume formation clearly over the island on the lee slope of the ridge line and the smaller southeastern peak. Note that cloud-top temperatures are colder at the plume source, immediately adjacent to the highest terrain—an indication of greater wave amplitude and highest cloud-top altitude in that region.

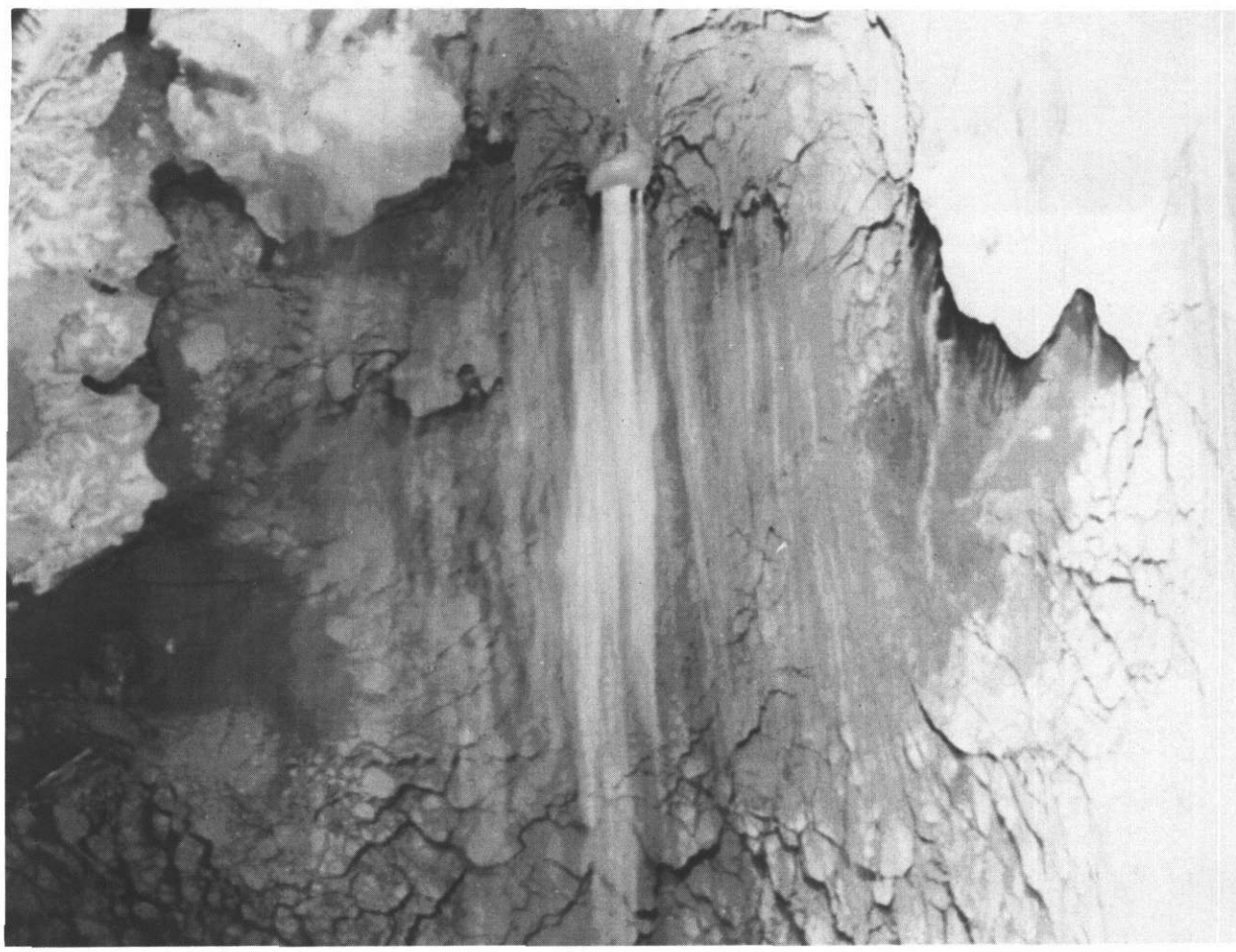

Figure 4-60. IR NOAA-10 (Channel 4) Imagery, 1515 GMT 28 March 1987.

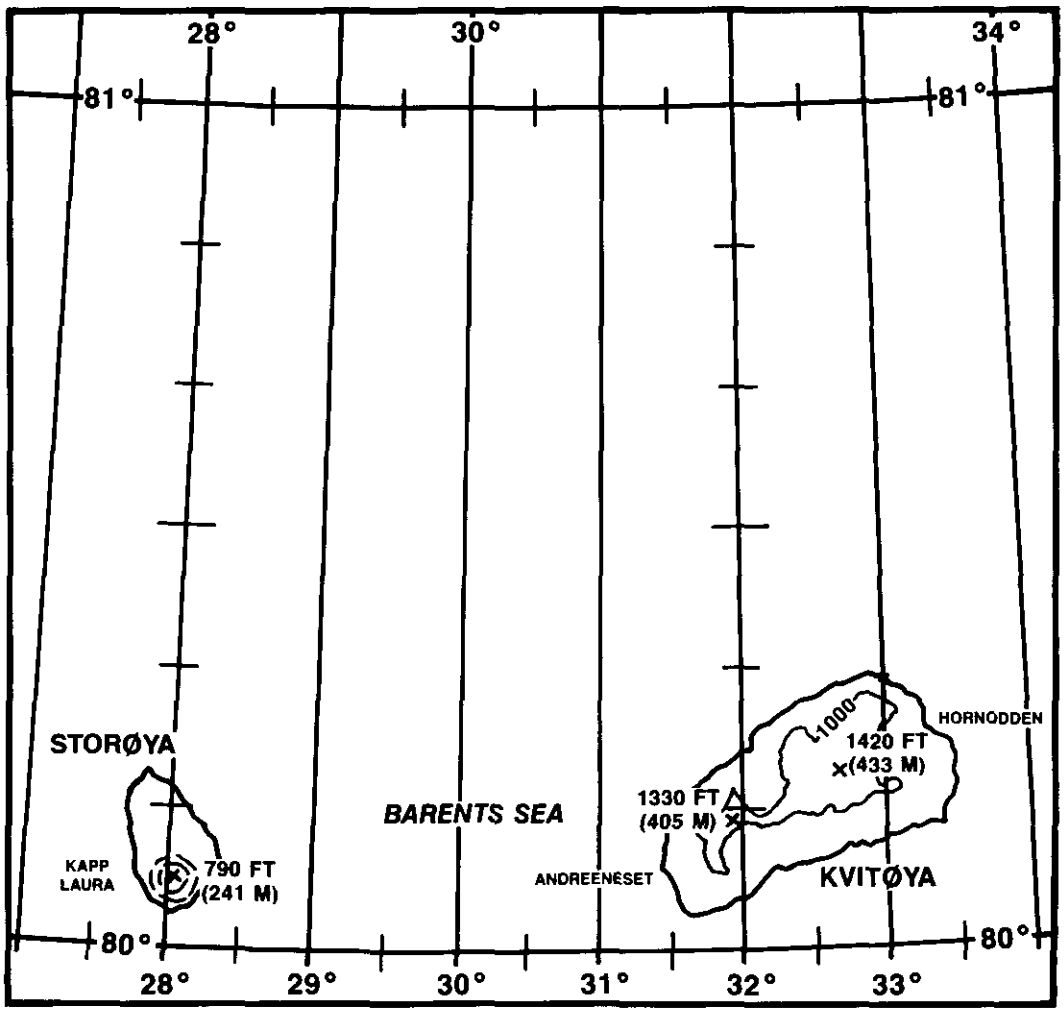

Figure 4-61. Map of Kvitoya Island.

4.5.3 Polynya Plume Examples

In the NOAA-10 satellite image of Fig. 4-60 some obvious small plumes emanating from lead features in the southeastern portion of the figure can be seen. Probable polynya plumes also extend from apparent open water areas south of Franz Josef Land in the upper right of the image. As indicated and illustrated in Chapter 5, Section 5.2, polynya-produced plumes in cold Arctic regions generally appear warmer than the surrounding, ice-covered sea surface over which they lie, due to formation under a pronounced low-level inversion. The plumes in Fig. 4-60 appear colder than the surrounding region. This illustration suggests that the air was more unstable than normal at lower levels and that the plumes were forming under an inversion base whose temperature was colder than the surface temperature.

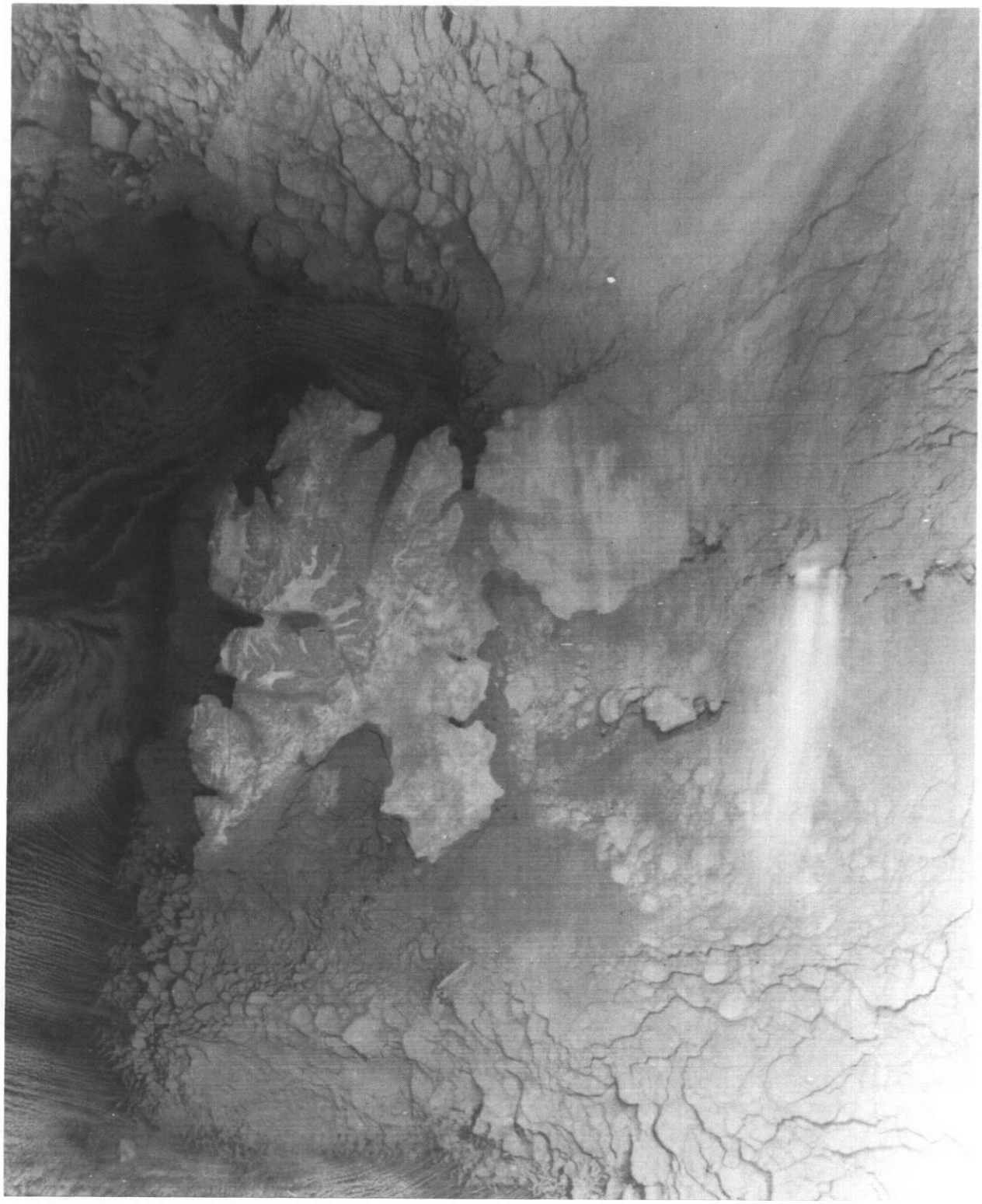

Figure 4-62. IR DMSP (Thermal Smooth) Imagery, 0254 GMT 28 March 1987.

A sounding for Heysa (Fig. 4-63), located at 80.6°N 58.0°E on Franz Josef Land, north of the polynya region, confirms this potential. Air from the north flowing from the ice over the open water of the polynya would be rapidly moistened and warmed by several degrees, depending on length and duration of the path over the water. Resulting plume formation would be capped near the base of the inversion, which is shown to be colder than the surface temperature.

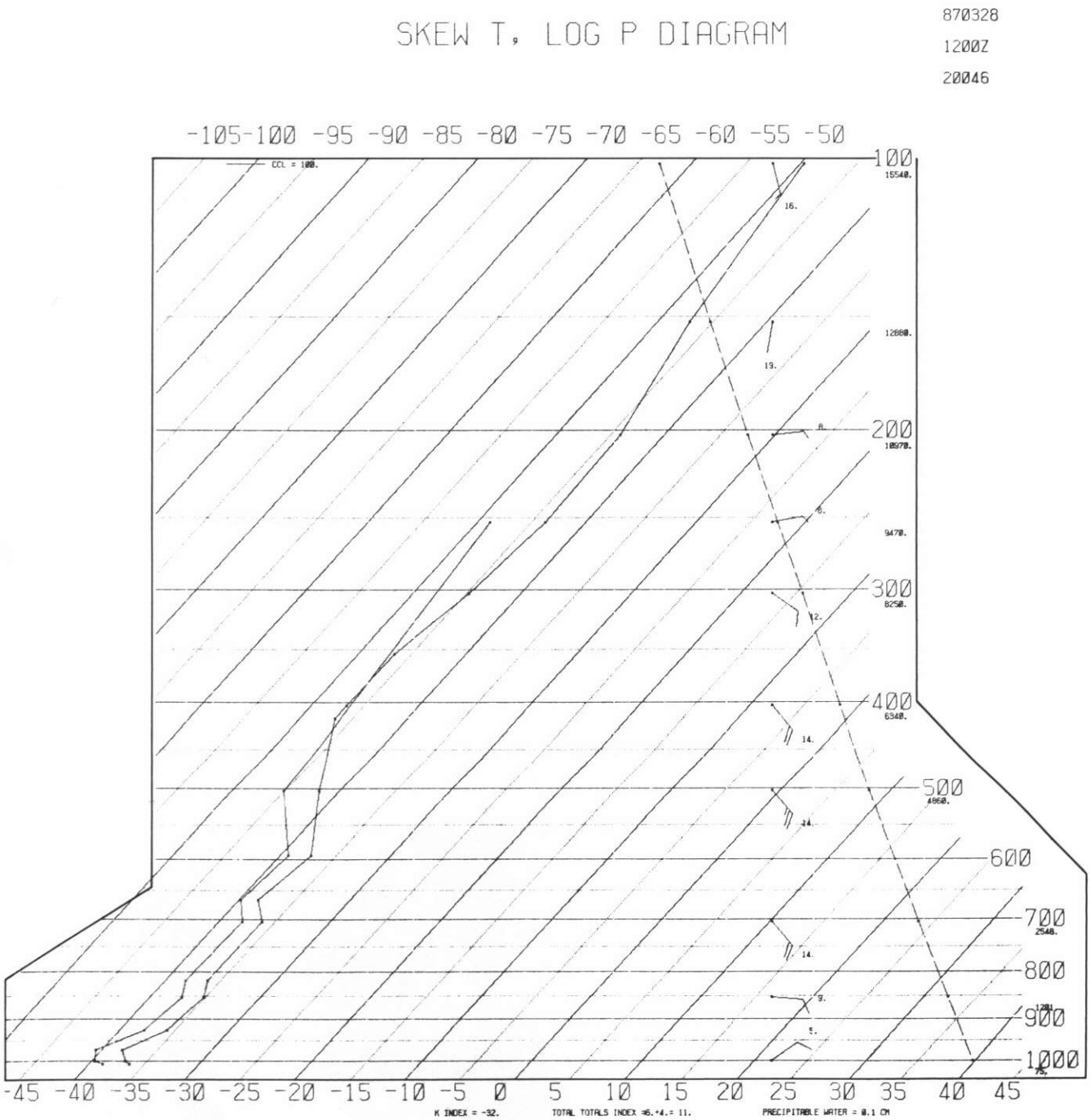

Figure 4-63. Radiosonde Data for Heysa (Station 20046), 1200 GMT 28 March 1987.

4.5.4 Association of Arctic Plumes and Arctic or Polar Frontal and Jet Stream Location

An examination of Arctic plume formation over the Svalbard-Barents Sea region (Fett, 1990(a)) showed that the plumes could often be used as indicators of Arctic frontal position and coexisting jet stream location. Plume generation requires strong winds aloft, and sufficient moisture, characteristic of frontal zones. Since Arctic fronts are often ill defined over the relatively flat ice surface, the sudden generation of a plume over mountainous island terrain may be an early unambiguous signal of Arctic frontal position.

Figure 4-64 exemplifies the concept for a polar front, slightly south of Arctic latitudes, over the Aleutian Islands area. The image is from IR DMSP thermal smooth (TS) data received at Elmendorf Air Force Base on 11 May 1990. Arctic plume generation is apparent over Unimak Island in obvious close association with a polar front position and accompanying low pressure center or cloud vortex. Note that plume formation at this time is restricted to Unimak Island, where the front is located, and not over equally mountainous terrain to the east-northeast or west-southwest. This fact makes the use of island plumes valuable in meteorological analysis. An additional excellent example of lee wave formation in association with an Arctic front is shown in Chapter 5, Fig. 5-16.

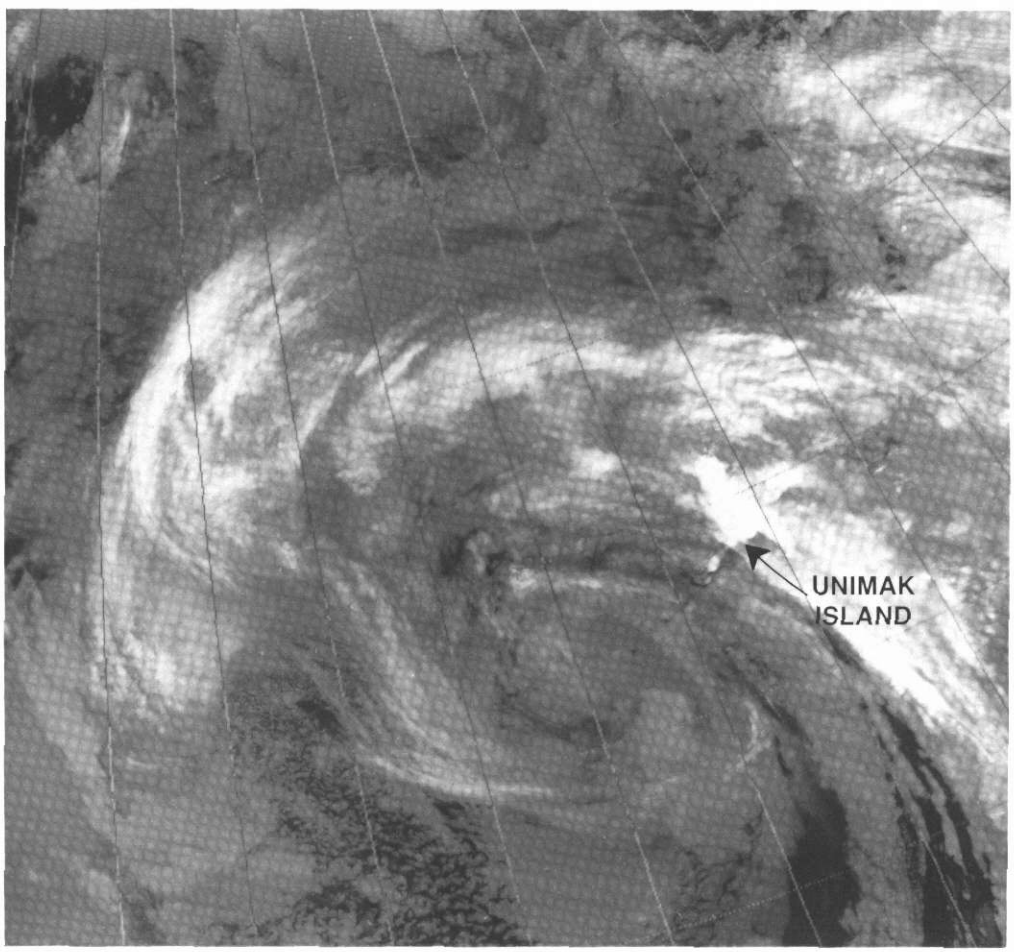

Figure 4-64. IR DMSP (Thermal Smooth) Imagery, 0613 GMT 11 May 1990.